ESC201T : Introduction to Electronics

Lecture 19: Semiconductors

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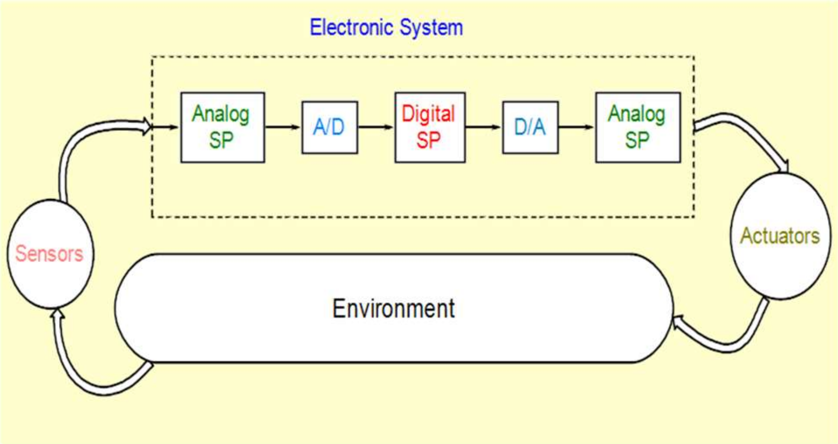
Course Objective : Learn how electronics enables use of electricity to solve problems



Learn how analog and digital circuits work

Learn by analyzing and designing analog and digital circuits

Tools for circuit Analysis

- ❑ Fundamentals of electrical circuits--3
- ❑ Transient Analysis of RLC Circuits--2
- ❑ Sinusoidal Steady State Analysis--4

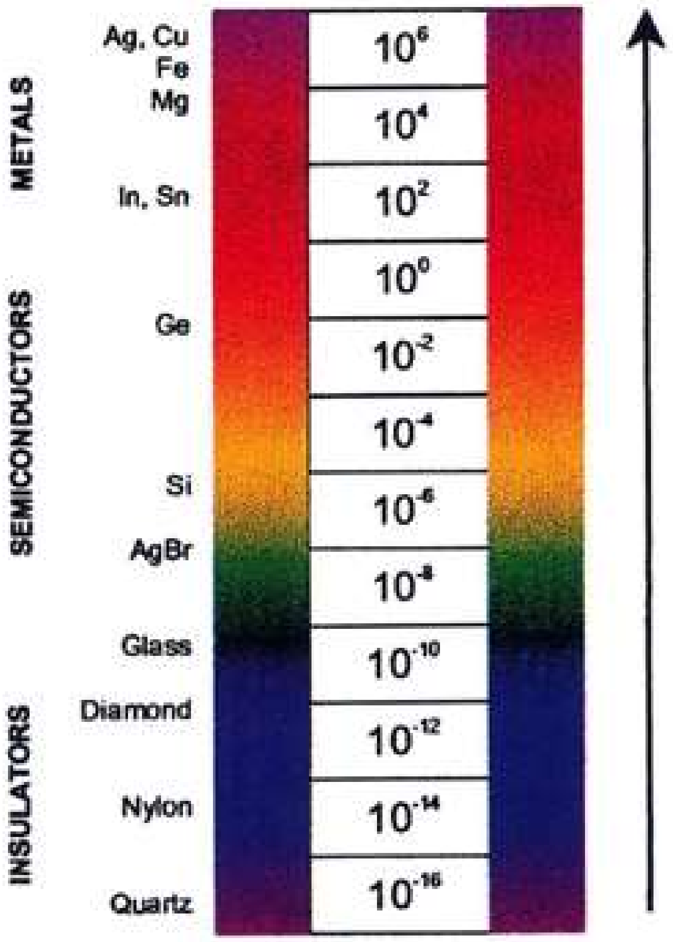
Analog Circuits

- ❑ Semiconductors, Diodes, Circuits-----3
- ❑ Transistors and Amplifiers---4
- ❑ Operational Amplifier based Analog circuits -4

Digital Circuits

- ❑ Logic gates, Combinational circuits ---4
- ❑ Flip-flops, Sequential Circuit---4
- ❑ Data Converters----3

Semiconductor



semiconductor

Conductivity (S/cm)

$Resistivity\ (\Omega cm)$

“Any sufficiently advanced technology is indistinguishable from Magic”

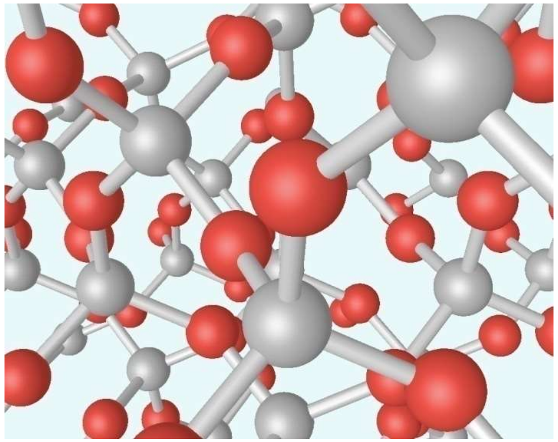
(“Profiles of the Future: An Inquiry into the Limits of the Possible”, by Arthur C. Clarke)

Semiconductors have allowed us to perform magic

Sand

Quartz

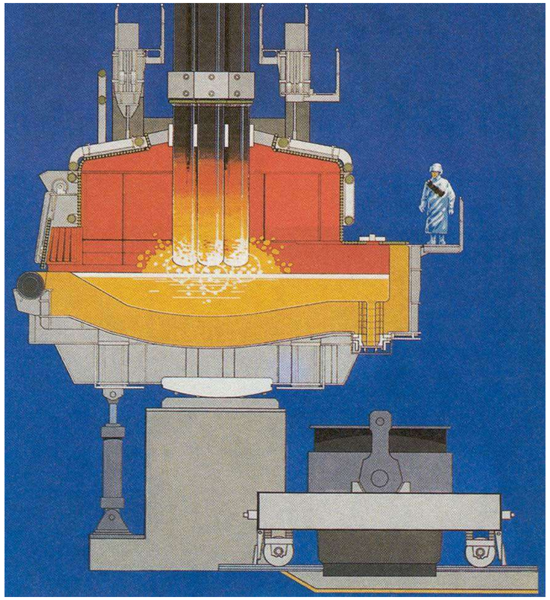
SiO_2



Quartzite

$SiO_2 + C \rightarrow CO_2 + Si$

Metallurgical Grade Silicon (95-98% pure)



About 60 000 tons of quartzite (about 45 per cent silicon) and 25 000 tons of charcoal (made from 90 000 tons of timber) are required to produce the 28 000 tons of silicon. About 13 megawatt hours of electricity to produce one ton of silicon. At the industry standard of A$0.06 per kWh, electricity represents around 40 per cent of the market value of silicon

Metallurgical grade Silicon

$$Si + 3\,HCl \rightarrow SiHCl_3 + H_2$$

Trichlorosilane

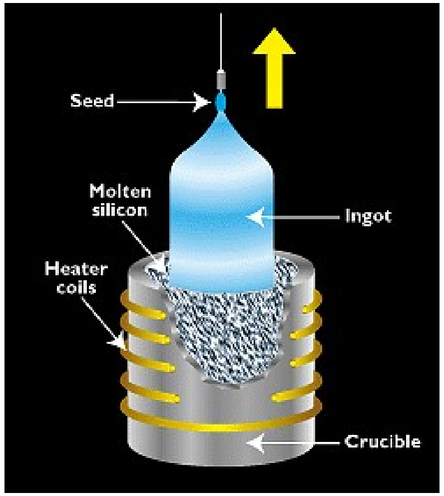
Vapor deposition

Electronic Grade Polysilicon

Electronic Grade Poly-Silicon

Pure Silicon Crystal

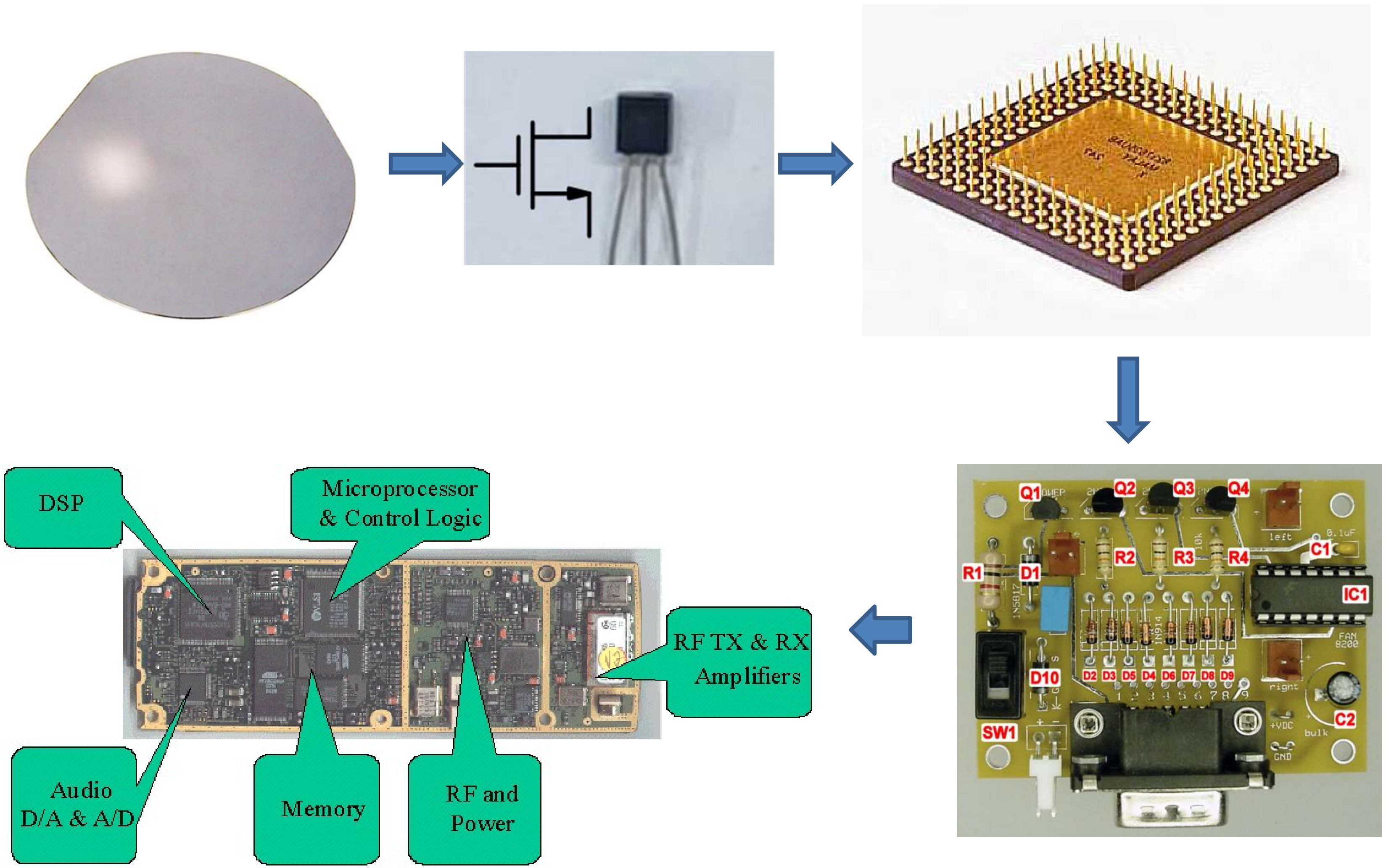
Silicon Wafer



~400um thick

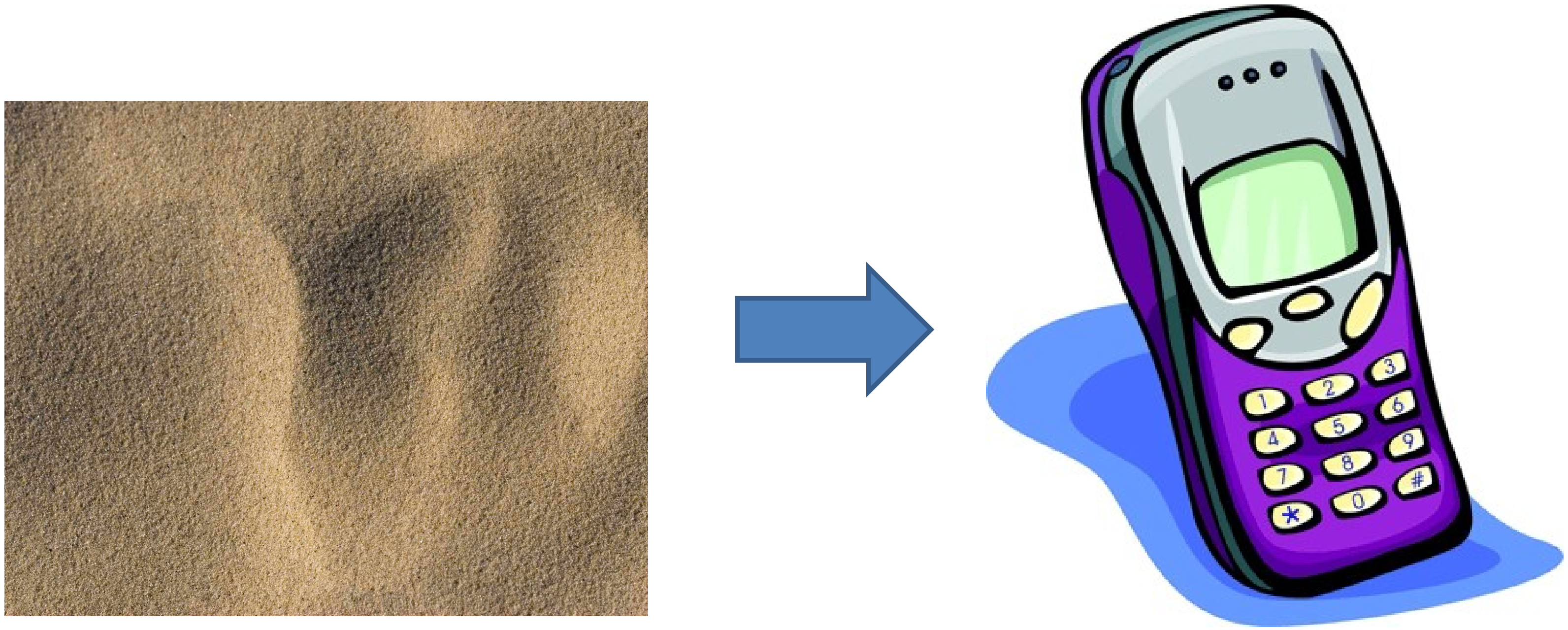
$1400/Kg !!

A 200mm wafer cost $45 in 2006

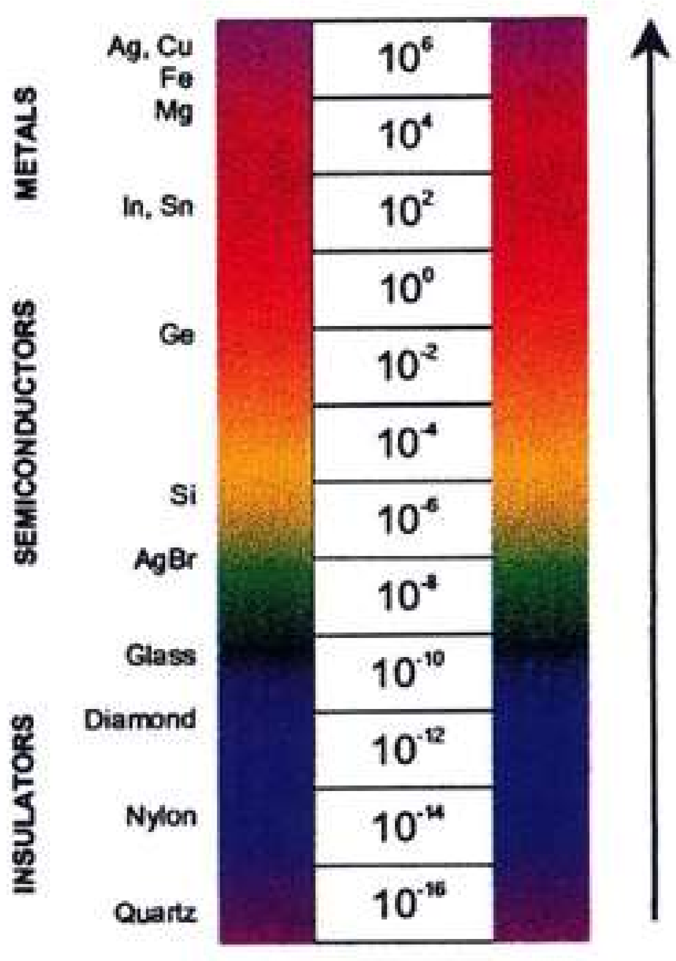


DSP
Microprocessor & Control Logic
RF TX & RX Amplifiers
Audio D/A & A/D
Memory
RF and Power

Electronics Revolution



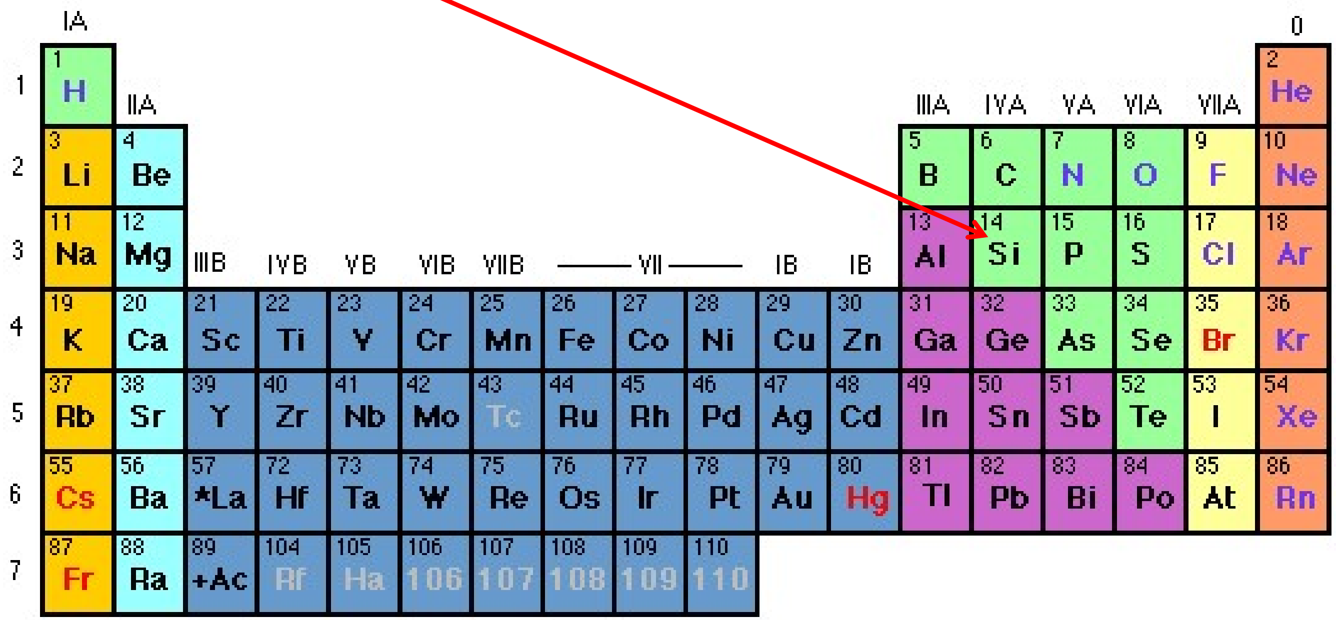
Silicon is a semiconductor



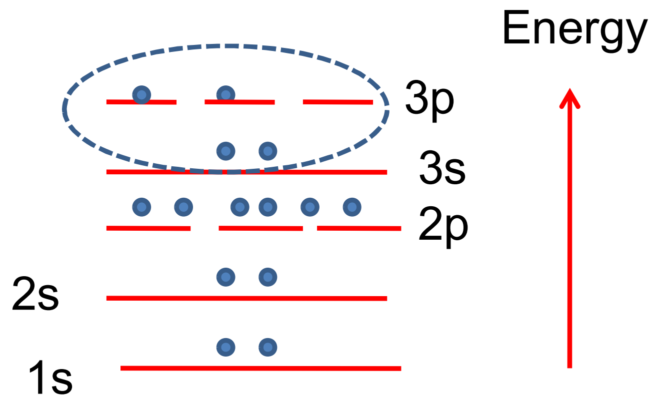
Conductivity (S/cm)

- ❑ More importantly, its conductivity can be altered and controlled
- ❑ It allows us to **control** current !

Silicon

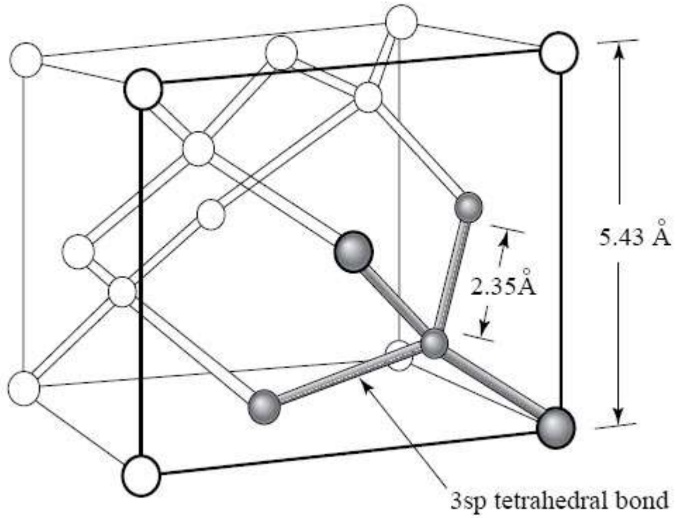


Electronic structure $1s^2 2s^2 2p^6 3s^2 3p^2$



4 outer shell electrons from 4 covalent bonds

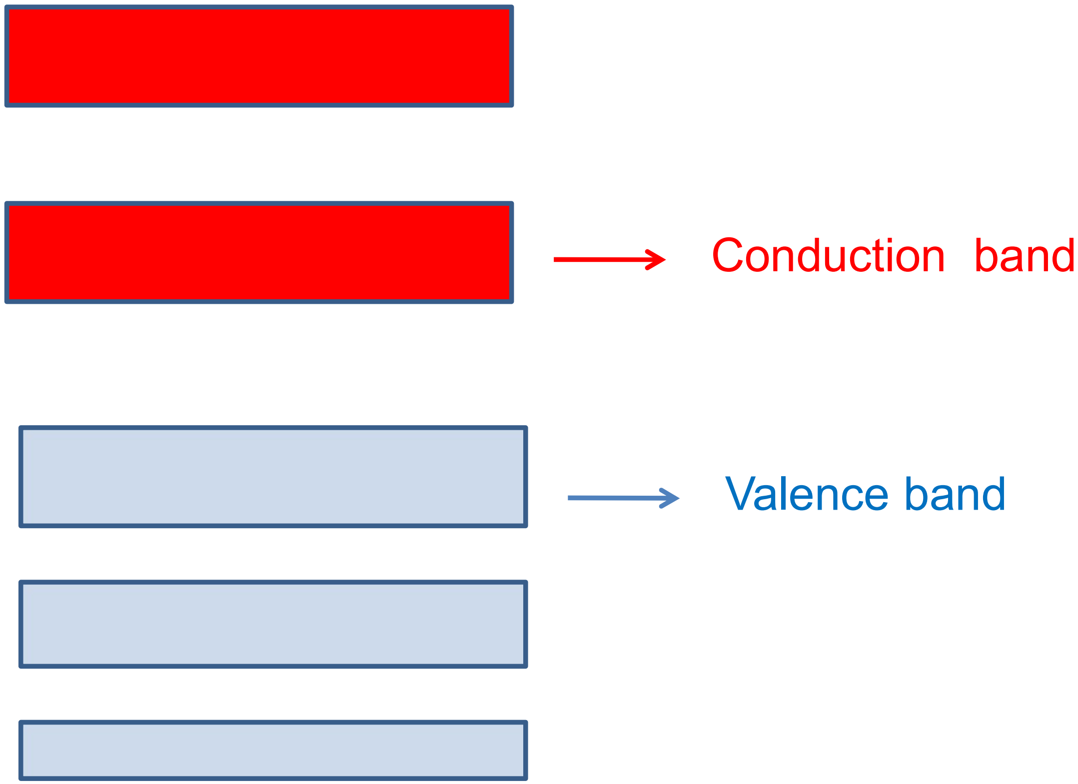
Silicon Crystal



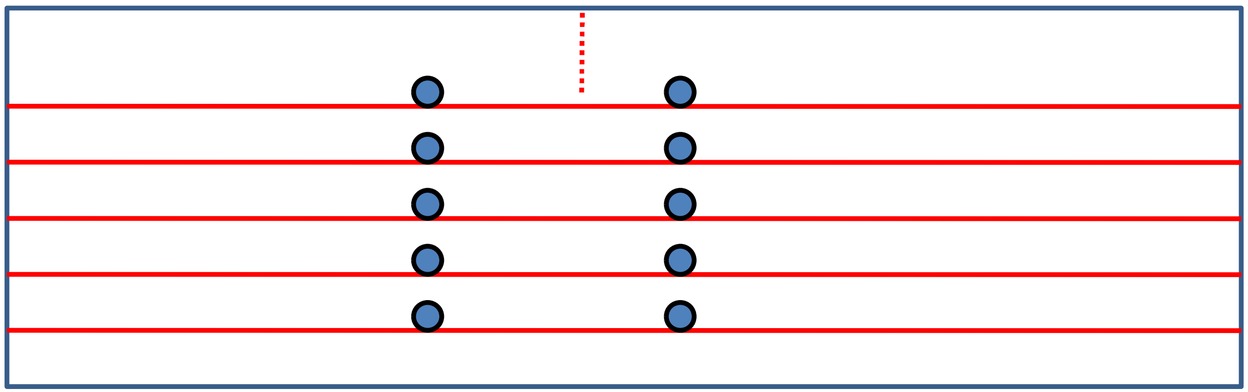
Electrons in a silicon crystal occupy bands of energies

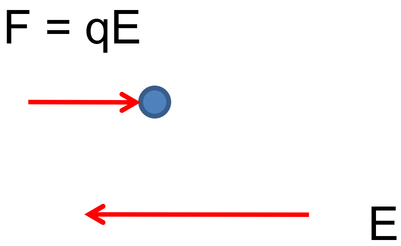
Bottom most empty band is called conduction band

Top most filled band is called valence band



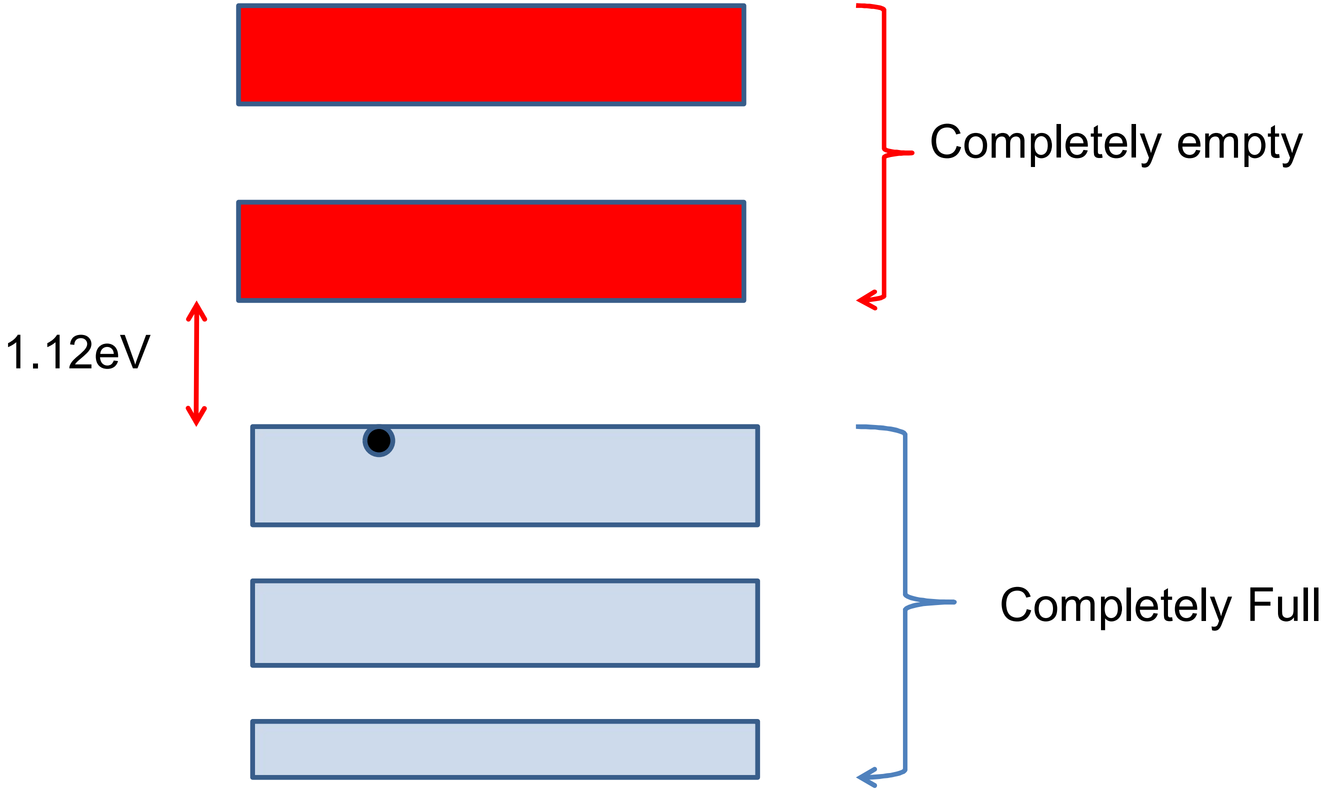
Electrons in a completely full band cannot contribute to current conduction !





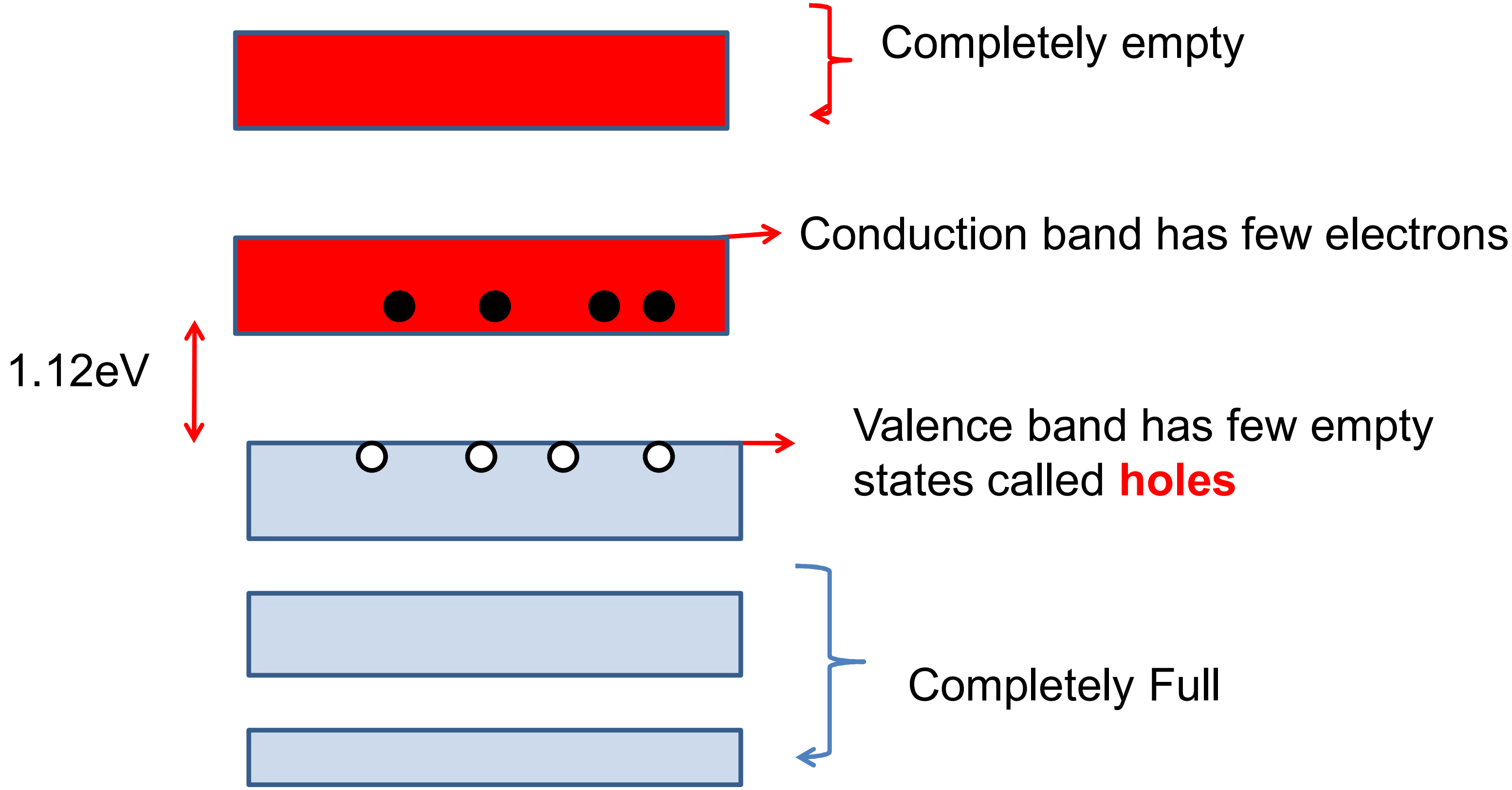
Energy of the electron should increase but all the higher energy states are occupied !

Picture of Silicon Crystal at 0^oK



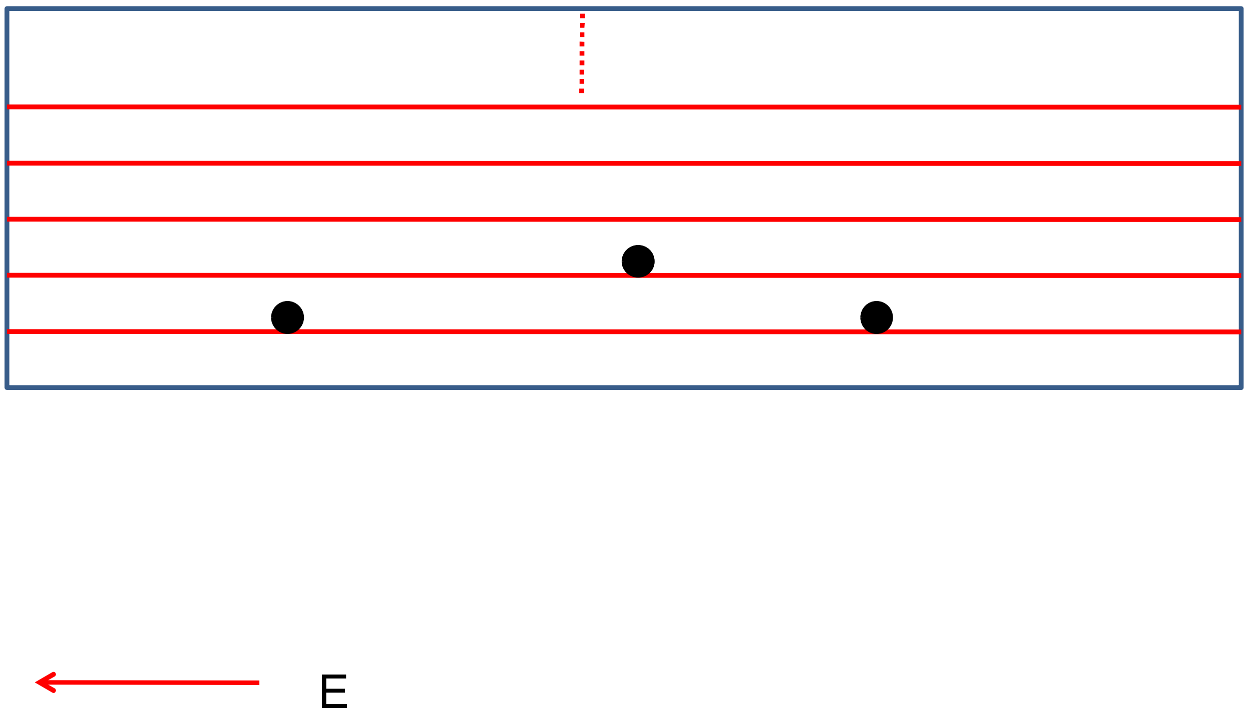
No current flows and Silicon acts like a perfect Insulator !

Picture of Silicon Crystal at 300^{o}K



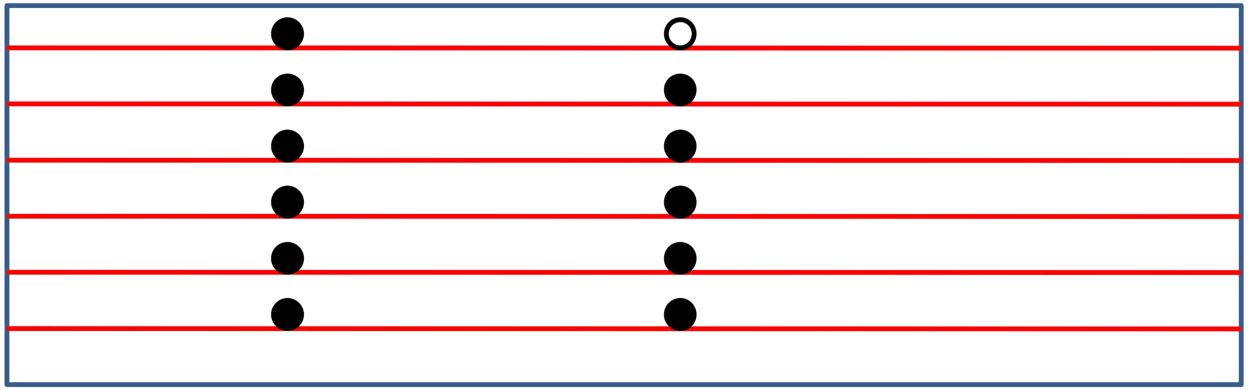
Electrons in conduction and valence band can now contribute to current flow

Conduction Band



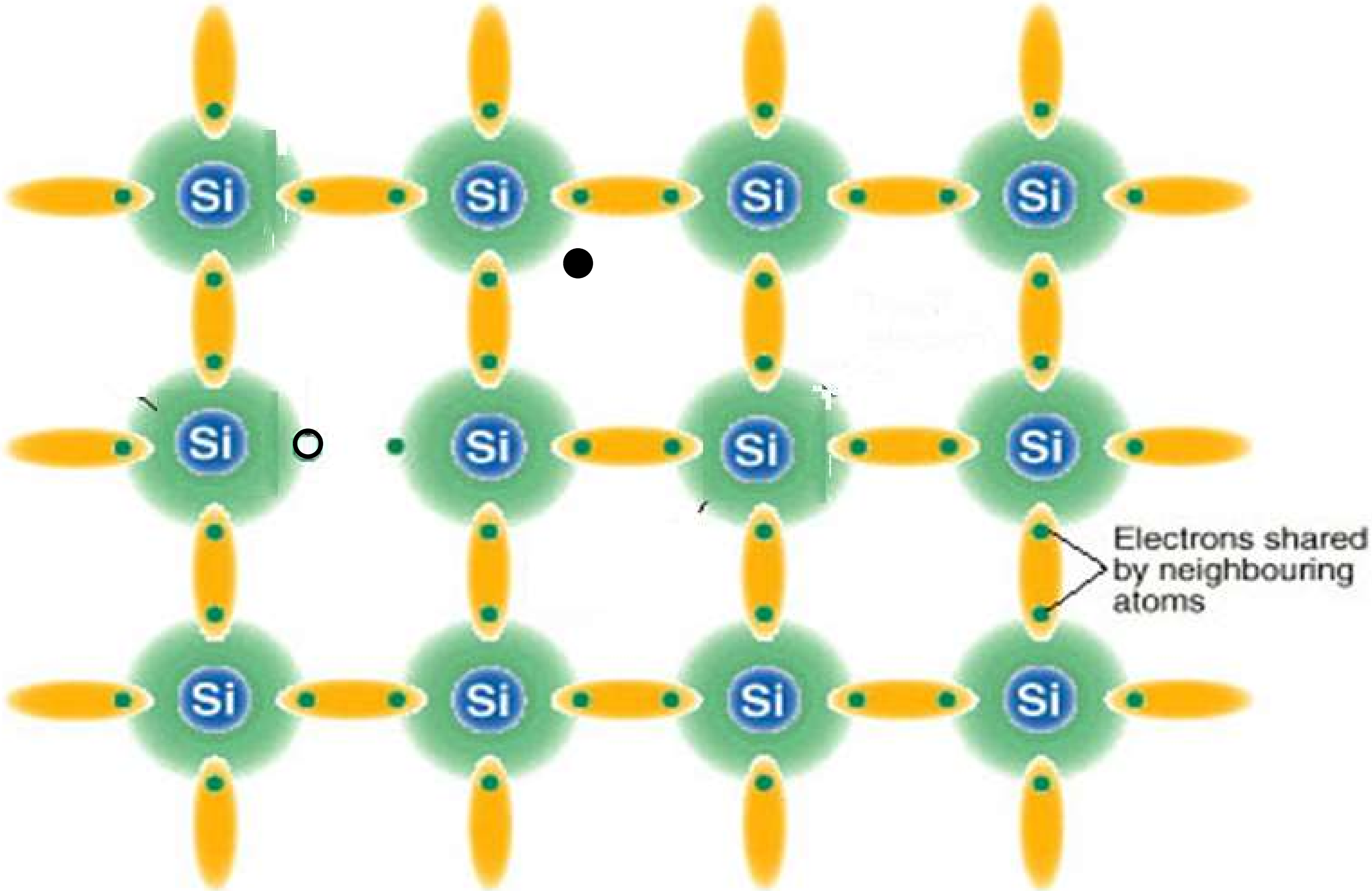
Conduction band electrons are free to move in whatever direction they wish

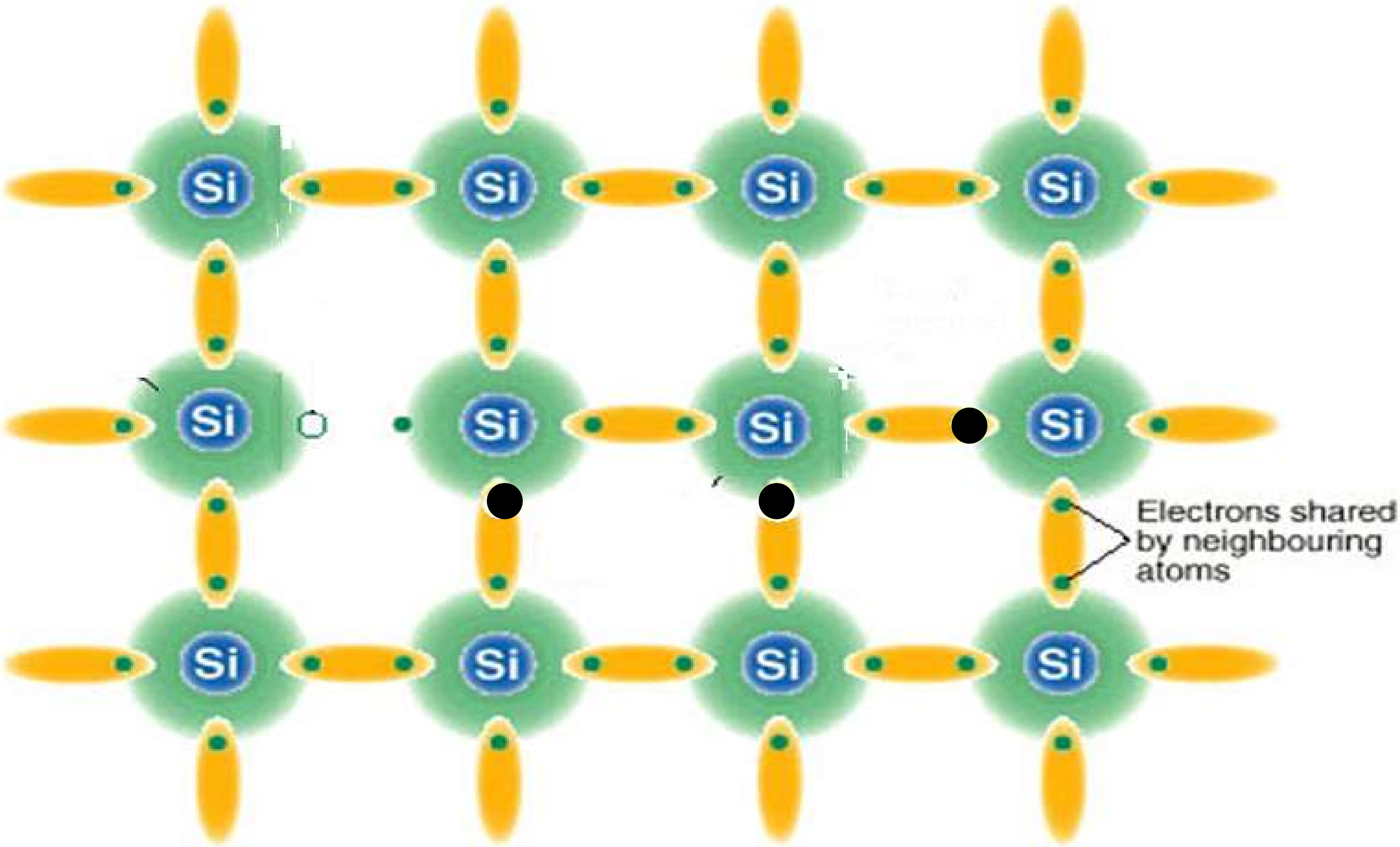
Valence Band



Electrons can now flow and contribute to current conduction

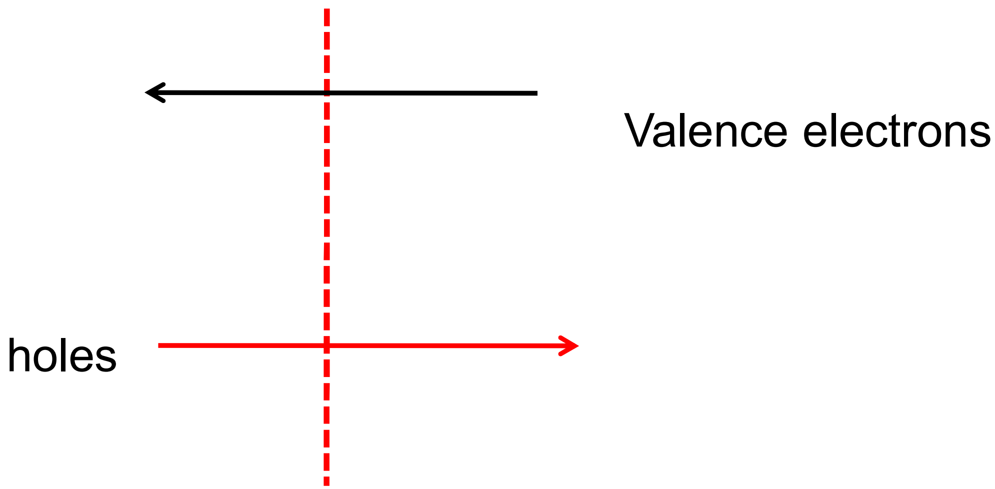
Simplified Picture




Si
Electrons shared by neighbouring atoms

The motion of valence band electrons is equivalent to motion of vacant states called holes

Suppose an n_v number of net valence band electrons cross the area from right to left in time t, then



$$I = -\frac{-q \times n_v}{t} = \frac{q \times n_v}{t}$$

It also means p = n_v number of holes cross from left to right in time t.

$$I = \frac{q \times n_v}{t} = +\frac{+q \times p}{t}$$

Current carried by electrons in valence band is equal to current carried by holes if we associate positive charge with them.

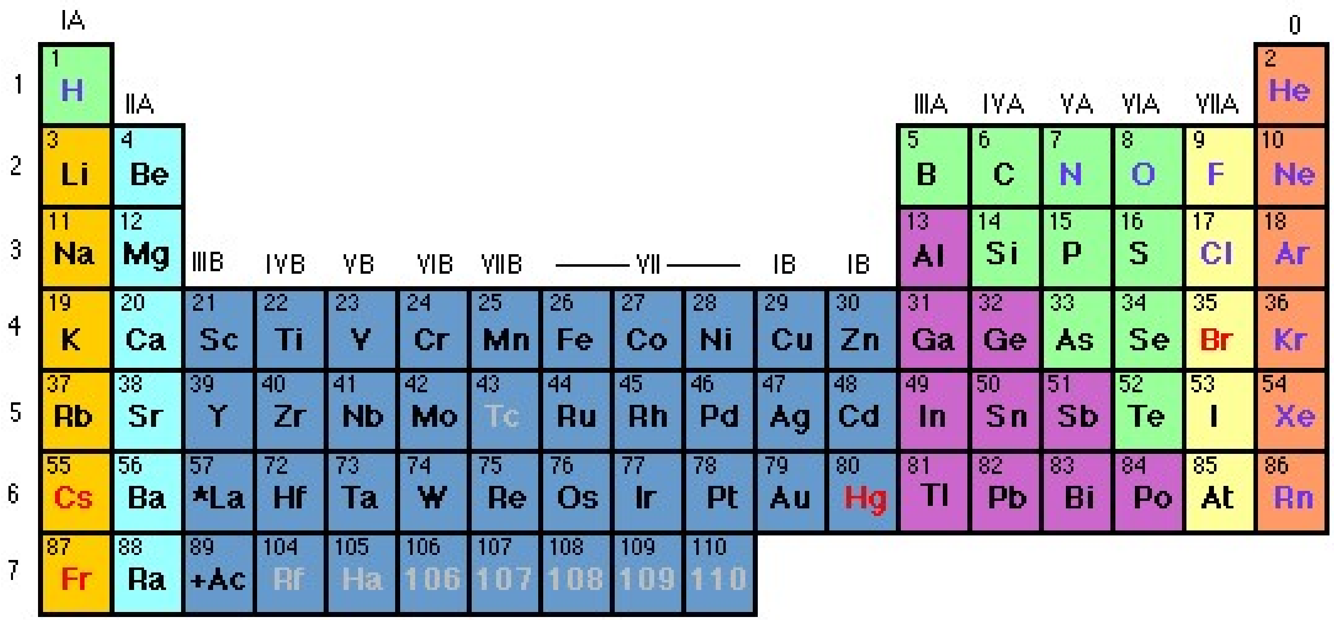
For the purpose of current flow and electronics in general, we can ignore the electrons in valence band and think only in terms of holes.

We should think of holes as particles carrying a positive charge of $+1.6 \times 10^{-19}$ C and moving in presence of electric field as electrons

To summarize, current in semiconductors is carried by electrons in conduction band and holes in valence band.

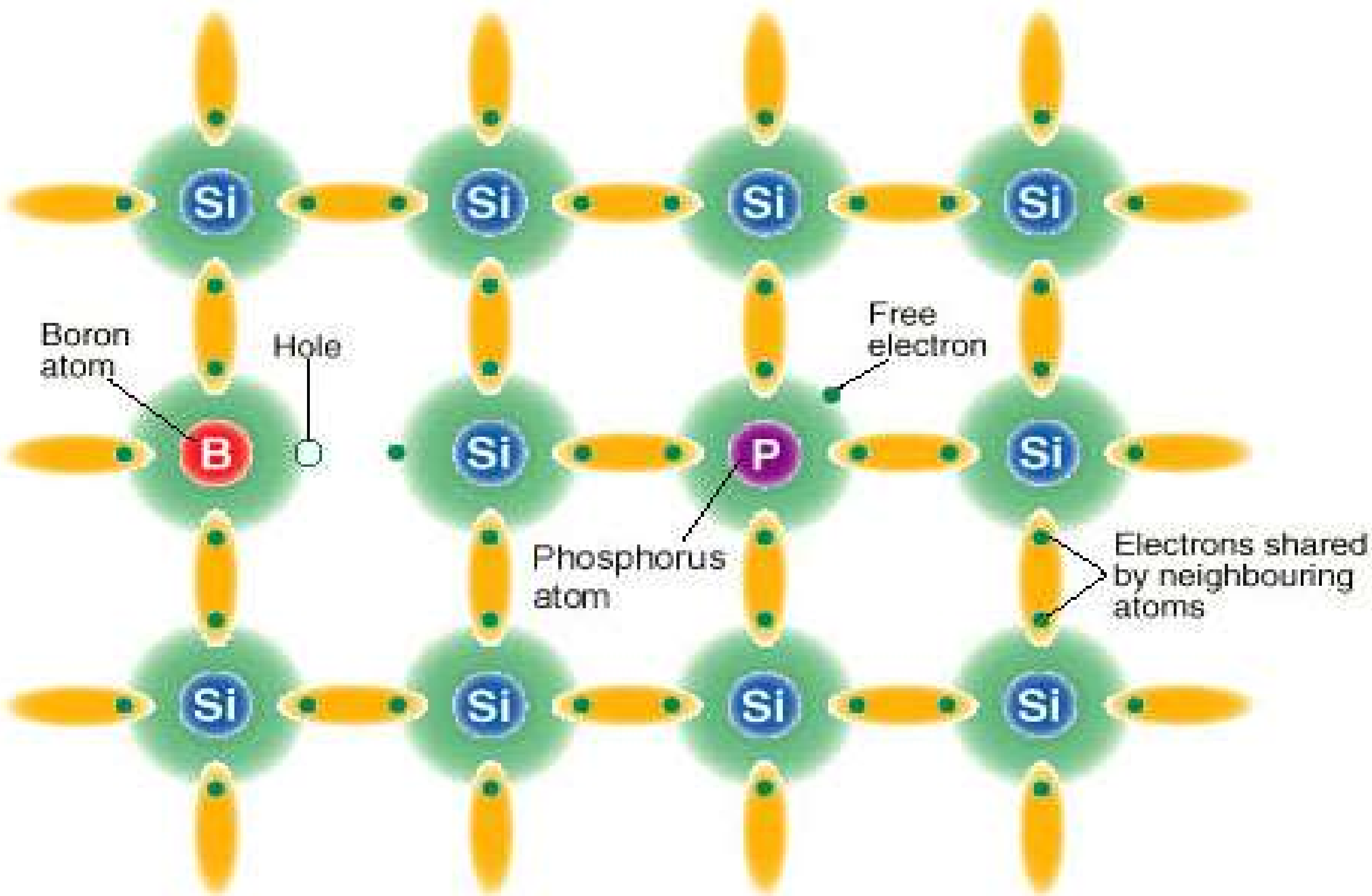
Extrinsic Semiconductors

Adding small amounts of suitable impurity atom can drastically alter number of electrons and holes in a semiconductor !



Addition of a group V element impurity to Silicon should increase electrons while addition of group III element impurity should increase number of holes

Doping



Si
Boron atom
B
Hole
Free electron
P
Phosphorus atom
Electrons shared by neighbouring atoms

N and P-type Semiconductors

N-type :   n > p

A Semiconductor such as Silicon doped with a donor impurity such as Phosphorous or Arsenic from group V of periodic table. The donor impurity donates an electron to conduction band thereby increasing their concentration

P-type :   p > n

A Semiconductor such as Silicon doped with a Acceptor impurity such as Boron from group III of periodic table. The acceptor impurity increases number of holes in valence band.

No. of silicon atoms per unit volume $\simeq 4 \times 10^{22} cm^{-3}$

Impurity concentration : $N_A = 10^{17} cm^{-3}$

1 in 400,000 Silicon atoms is replaced by Boron

Very small amounts of impurity atoms can cause a drastic change in electrical property of a semiconductor.

This is one of the reasons why even though sand is plentiful and 'dirt cheap', electronic grade silicon is so expensive

Silicon is one of the purest material on earth !

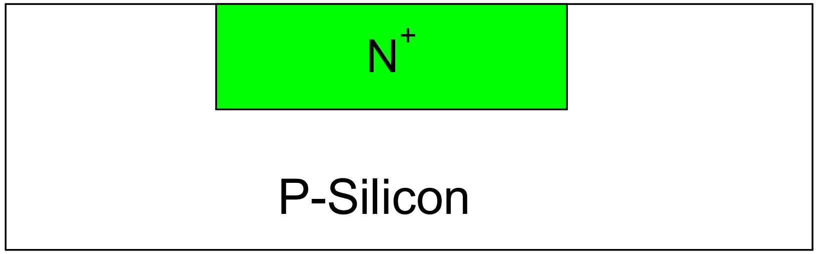
Clean Room

ISO 14644-1 cleanroom standards

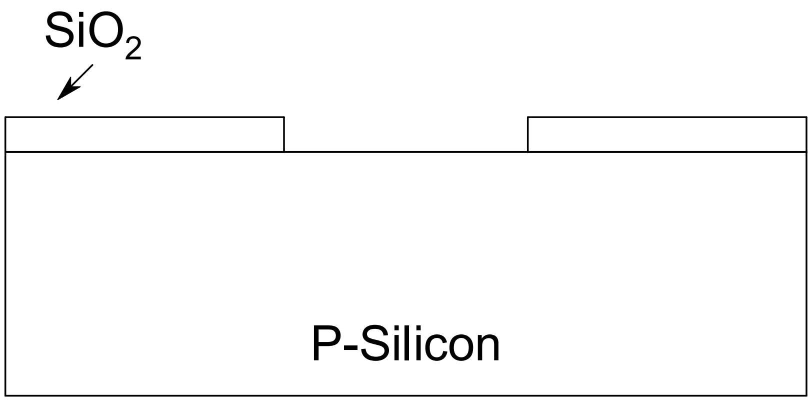
Class	maximum particles/m³						FED STD 209E equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10	2					
ISO 2	100	24	10	4			
ISO 3	1,000	237	102	35	8		Class 1
ISO 4	10,000	2,370	1,020	352	83		Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000
ISO 9				35,200,000	8,320,000	293,000	Room air

$1\ m^3 = 35.2\ ft^3$

•Suppose we have a Silicon wafer which is P-type and we wish to create a region within it which is N-type as shown below:



•This can be done by carrying out **diffusion/implantation** of N-type dopant in the structure shown below.

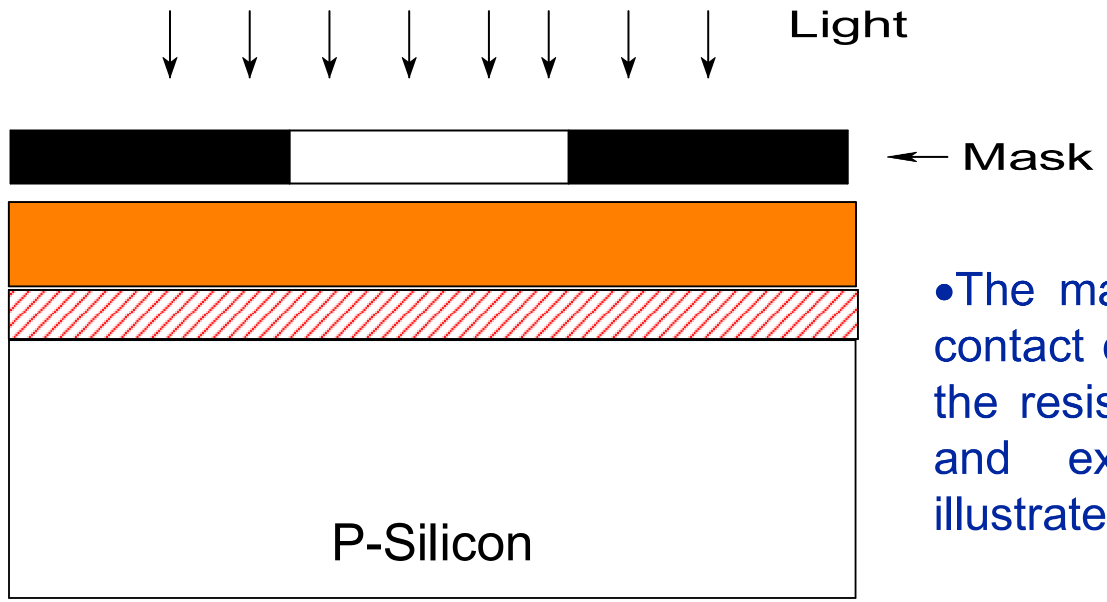


•The SiO_2 acts a as a barrier and prevents diffusion of dopants through it . As a result the N-type region is created only in the region where Silicon is exposed

•A window in SiO_2 can be created by first covering the whole Silicon surface with oxide through the **oxidation** process.

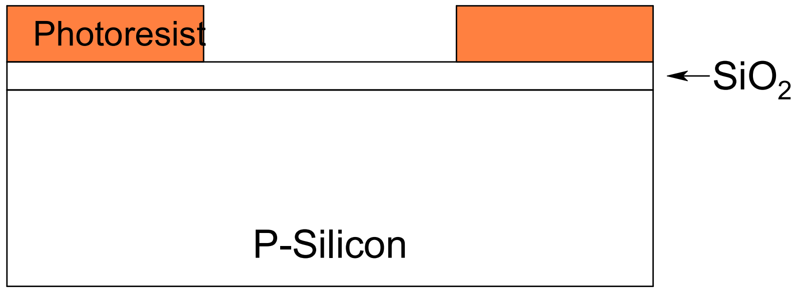
•Next the Silicon surface is coated with an organic material which is sensitive to light called **Photoresist**. A positive photoresist undergoes changes upon exposure which makes it easier to dissolve in a developer solution

•We next need a **Mask** which specifies the location and dimension of N-region. It is basically a glass plate which has opaque and transparent regions. Wherever we want the photoresist to remain, that region is opaque and wherever we wish to remove the photoresist that region is made transparent.

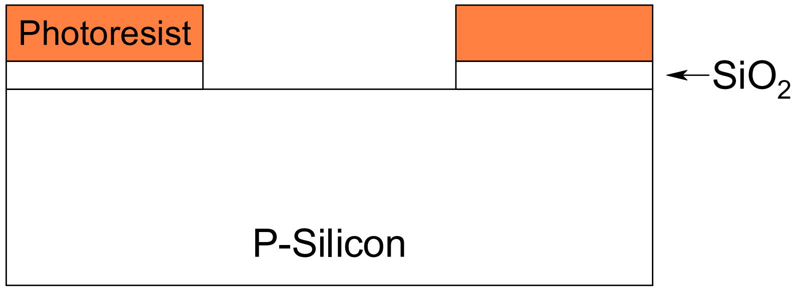


•The mask is placed either in contact or in close proximity to the resist coated Silicon wafer and exposed to light as illustrated below

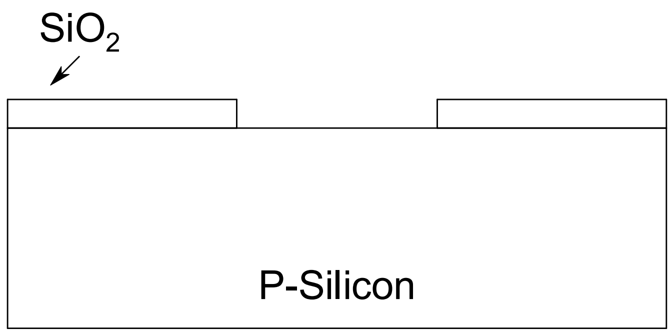
•After this step of **Photolithography** , the exposed photoresist is removed using a developer solution and we obtain the following structure:



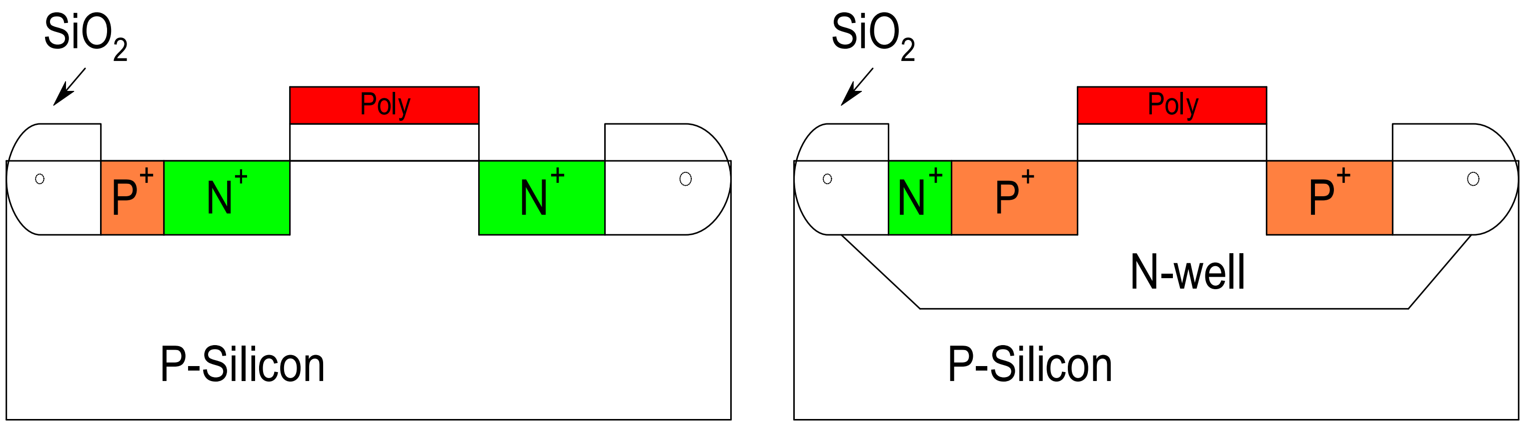
•Next the whole wafer is dipped in HF acid to **Etch** the exposed oxide to obtain the following structure:



•Next the photoresist is removed to obtain the structure required for carrying out diffusion.



Fabrication: simplified view



- Transfer of pattern from **mask to photoresist ----photolithography**

- Transfer of pattern from photoresist to silicon

- Various processing steps.